DOE Wind Program Testing Activities

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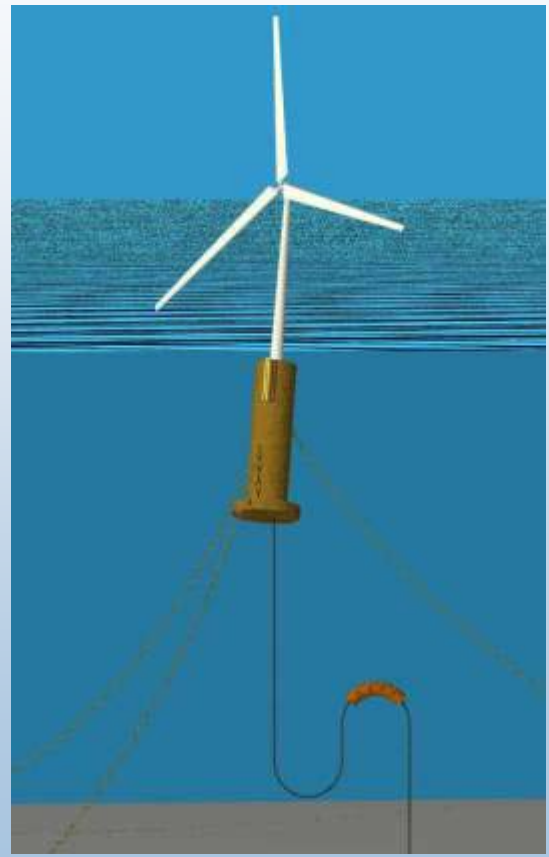
FY2005 DOE Wind Program Implementation Meeting

November 18, 2004

DOE Wind Program Testing

- Overview of capabilities, support activities & projects
- Mission need, federal role, risks
- Issues & concerns
- Future Plans
  - Interim stop-gap blade testing
  - Large Wind Turbine Test Facilities (LWTTF) – Jim Johnson
  - Offshore dynamic testing requirements - Sandy Butterfield



Testing Overview

- Test Capabilities:
  - Structural
    - Blades, components
  - Dynamometer
    - Drivetrains, gearboxes, motors, power electronics
  - Field
    - Full-scale turbine systems, prototype turbines, wind farm monitoring, Hybrid Systems, R&D
- Support development & evolution of international test standards
- A2LA accreditation
  - recognized by certification and financial institutions (conform to IEC, UL, GL)

A2LA ACCREDITED

Structural Testing Capabilities

- Blades (3 test facilities)
  - Fatigue
    - Single or dual axis (flap and edge simultaneously)
    - New Blade Resonant Excitation (B-REX) system
  - Static, ultimate strength
  - Displacement, stiffness, strain, modal
  - Support advancement of blade structural models, design tools, NDE, and design methods.
- Components
  - Load frames
  - Small blade test stand

Structural Testing Projects

- Recent
- In Progress
- Upcoming

IUF (32 m +)	251 Highbay & A-60 (19 m)	Small blade stand, load frames, misc.
GE 34c 1.5 MW* CRADA (Mar 2004, 7 months)	NPS-100* Sandia BMI (2003)	SWWP H-40 rotor CRADA (2003)
TPI 44.7 m 2.5 MW CRADA (Oct 2004, 5 months)	K&C 56-100 root WFO UL (Nov 2003, 1 month)	Bergey XL-50 blades* DWT (2004)
GE 1.5 MW carbon* CRADA (Mar 2005, 2 months)	3Tex 10m carbon spar SBIR (Jan 2005, 2 months)	SWWP Storm blades #1* DWT (July 2004, 5 months)
3Tex 10m carbon spar SBIR WFO (May 2005, 1 month)	TPI CX-100 9m* Sandia (Mar 2005, 2 months)	Renew A2LA structural testing accreditation*
Clipper 45m* LWST (June 2005, 4 months)	TPI TX-100 9m* Sandia (May 2005, 2 months)	SWWP Storm blades #2* DWT (Early 2005, 2 months)
Wetzel Bend-Twist SBIR WFO (Oct 2005, 2 months)	TPI WindPACT* Sandia (July 2005, 2 months)	TPI/ NPS studs DWT (Early 2005, 1 month)
GEC Bend-Twist SBIR WFO (Dec 2005, 3 months)	LWST Ph. II Component* LWST (Sept 2005, 4 months)	
LWST Ph. II Component* LWST (March 2006, 4 months)		

*Program Milestone

Structural Testing Facility Upgrades

- Recent
- In Progress
- Upcoming

IUF (32 m +)	251 Highbay & A-60 (19 m)	Small blade stand, load frames
B-REX increased mass & accumulation	Dual-axis forced-hydraulic test system	Small blade test stand
Test stand posterior attachments	DAS channel # & hardware	
DAS channel # & hardware	Smaller B-REX	
Test stand face welds		
B-REX for single-axis edgewise testing		
Temporary outdoor 50m blade test stand*		
Large blade handling hardware (move, rotate)		

*Program Milestone

Dynamometer Testing Capabilities

- Drivetrains (large & small dyno test facilities)
  - Gearboxes
    - Gear contact pattern, fatigue
  - Motors
  - Power electronics systems & controls
- Drivetrain system integration
- Component & system efficiency
- Endurance
- Safety & function
- Condition monitoring
- High-speed data acquisition
  - Gear strain, electrical waveforms

Dynamometer Testing Projects

- Recent
- In Progress
- Upcoming

2.5 MW Dyno		Small Dyno (225 kW) (Under development)
Clipper DGD-1 1.5 MW* LWST (Mar 2003, 17 months)		SWWP Storm 1.8 kW DWT (2005)
Clipper DGENQ 2.5 MW* LWST (Aug 2004, 6 months)		NPS-100 100 kW DWT (2005)
GEC 1.5 MW SS gearbox, MS PM generator* WindPACT (Feb 2005, 3 month)	GE Wind 1.5 MW SLE 77m drivetrain CRADA (3 months)	University Subcontracts
NPS 1.5 MW DD PM generator* WindPACT (May 2005, 3 months)	GE Wind 1.5 MW XLE 82m drivetrain CRADA (3 months)	
NPS 1.5 MW PE* LWST (June 2005, 3 months)		

?

*Program Milestone

Dynamometer Testing Facility Upgrades

- Recent
- In Progress
- Upcoming

2.5 MW Dyno	Small dyno (225 kW) (Under development)
Gearbox re-ratio to increase power output needed to test 2.5 MW drives*	$200K NREL General Purpose Plant funding approved – connect to turbine bus to enable regeneration
Full-torque direct LSS calibration system	Interconnection switchgear
690 VAC transformer regeneration loop*	DAS upgrade
DAS channel #, sample rate & hardware	

*Program Milestone

Field Testing Capabilities

- Full-scale turbines
  - NWTC or industry partner sites
- Typical types of tests:
  - Accredited Loads, Power Performance, Acoustic Noise, Power Quality, Duration, Safety and Function
- Custom testing to meet R&D objectives
- Hybrid power test bed
  - Hydrogen electrolyzer, desal, fuel cells…
- Wind farm data monitoring
- Development of data acquisition systems for industry use
- Testing & certification training

Field Testing Projects

- Recent
- In Progress
- Upcoming

LWST	DWT/ Hybrid	R&D, Misc.
GE Wind - Anemometer comparison* – 3 sites	NPS NW-100 loads* - NWTC	ART/ CART, SWWP Air, NPS, SWRT – data for aeroacoustics code validation* - NWTC
GE 1.5 MW loads (with UL)	SWWP H-80 tower loads - NWTC	Small Wind Research Turbine (SWRT)* NWTC
Wind farm monitoring* for Systems Integration	Bergey XL.50 loads test set-up* - NWTC	Controls Advanced Research Turbine (CART)* - NWTC
Clipper LWST site cal*	Hydrogen electrolyzer* – NWTC HPTB	GE Wind/ Sandia Lamar Low Level Jet Project*
Clipper LWST loads*	SWWP Storm loads* - NWTC	Renew A2LA structural testing accreditation*
GE Wind LWST loads*	NW Seed RFV* – Bergey XL.10	Wind Turbine Company 250 kW POC restart
	DWT Phase I Projects*	3-bladed CART* – NWTC

*Program Milestone

Mission Needs

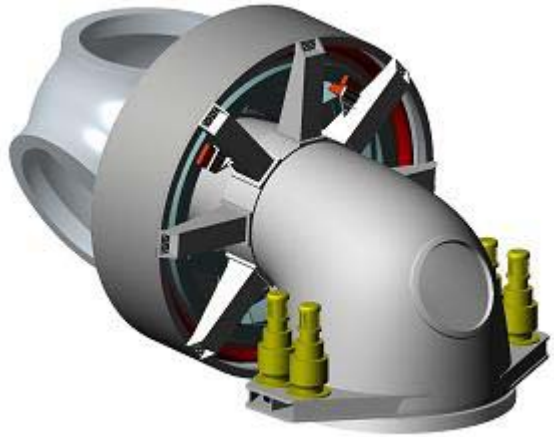
- Testing is a critical element of Wind Program LWST and DWT technology development
  - Decade of industry reliance on facilities & support
  - Essential to minimize risk of latent design flaws resulting in costly fleet-wide retrofits

- Pathways for Wind Program goals outstrips existing testing capability
  - To achieve LWST cost reduction goal, industry is scaling to megawatt scale turbines – 2.5 to 5MW range
  - NWTC infrastructure and testing facilities are not adequate to support the LWST goals

Issues & Concerns

- Prioritizing test projects
- Mitigating test delays
  - Accommodating partner needs:
    - Project priority shifts
    - Resource problems
- Reductions in NWTC test staff
- Large Wind Turbine Test Facilities (LWTTF)
  - Proposed 8 MW Dyno and 70m blade testing
  - Expected FY'08 at earliest
    - Interim solutions

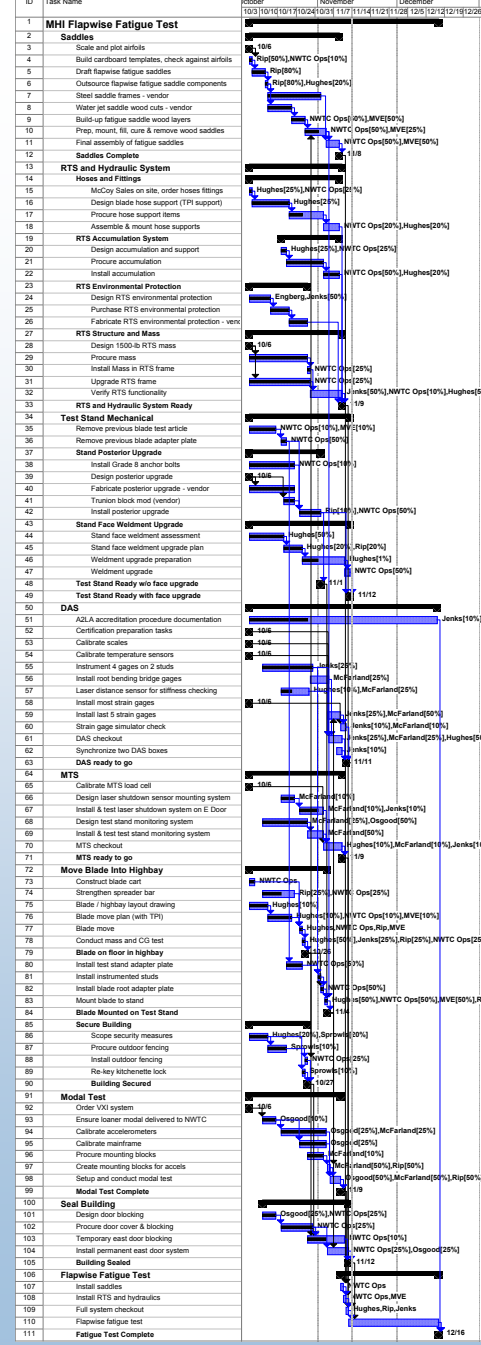
Issues & Concerns: Factors to Consider in Prioritizing Test Projects



- Projects supporting Wind Program goals
  - LWST and DWT technology development
  - Quantify progress (ATTU)
- Projects to help leverage development of new test capabilities
  - Anticipated needed to support Program goals
  - Opportunity to offset costs through fee-for-services testing (CRADA or WFO)
- Projects supporting industry partner needs
  - Certification, risk mitigation, performance characterization
  - Opportunity to offset costs through fee-for-services testing (CRADA or WFO)

Issues & Concerns: Recommendations for Mitigating Test Delays

- Designate single points of contact
  - At NREL and at industry partner organization
  - Especially if multiple test activities
    - Establish priorities
    - Main conduit for test planning and coordination
  - Work for quick resolution of unplanned problems
    - Test plan deviation, failures, payment issues
- Maximize facility utilization
  - Prior to test installation in facility
    - Complete agreed-upon detailed test plan
    - Verified test support apparatus
    - Receipt of agreed-upon cost sharing (CRADA, WFO)
  - Remove test article if down time exceeds predefined limit



Issues & Concerns: NWTC Testing Staff Reductions

- Reduced from 16 to 12 FTE's
  - 3 test engineers & 1 technician departed
  - 5 test engineers & 7 technicians remain
  - Replaced departing post-doc with BSME intern
  - Retain 4 subcontracted support technicians
- Solution:
  - Request increased up-front test support from industry partners:
    - Test planning
    - Engineering, construction, & delivery of test support apparatus
    - Delivery of instrumented test articles
  - Minimize NREL engineering & technician needs during testing
    - Partner commits staff to provide agreed-upon level of test support
  - Continuing to transition certification field testing to industry
    - Maintain minimal core competency in most areas
    - In-house focus on loads testing
    - Train industry partner staff to conduct own testing

Large Wind Turbine Test Facilities

1989
FIRST BLADE TEST FACILITY IN USA

1996
INDUSTRIAL USER FACILITY TESTING FOR BLADES UP TO 37-METERS

1999
DYNAMOMETER TEST FACILITY FOR TURBINES UP TO 2.0-MW

2008
NREL LWTTF
8 MW DYNO
70-M BLADES

Wind Turbine Size

NO LARGE TURBINE TEST FACILITIES EXIST IN THE USA

Average Commercial Turbine Sizes

1989	1996	1999	2003	2005	2010
100-kW	500-kW	750-kW	1500-kW	2500-kW	>5000-kW
9-METER BLADES	19-METER BLADES	24-METER BLADES	37-METER BLADES	45-METER BLADES	70-METER BLADES

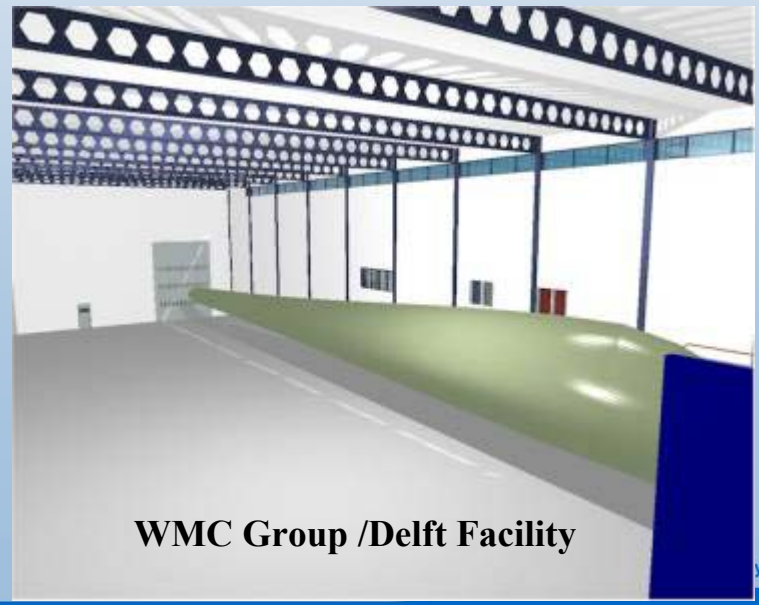
Federal Role in Providing Test Facilities

- An open, accredited, third-party testing facility is needed for both large and small wind companies to remain competitive with European manufacturers by
  - Validation of designs to reduce risks
  - Meeting certification requirements for domestic and international sales
- Most U.S. wind turbine manufacturers and component suppliers lack sufficient capital to develop suitable test facilities on their own
  - Multiple U.S. manufacturers are needed for mission success and for a strong, competitive industry

European Blade Testing

- Risoe National Laboratories – Denmark
  - Fee for service – government facility
  - Blades up to 45-meters
- LM Glasfiber – Denmark
  - Private facility
  - Blades up to 55-m
- NEG Micon – UK
  - Private Test Facilities
  - Formerly WEG/Aerolam
  - Blades up to 40-m
- WMC-Group / Delft University- Netherlands
  - Government funded / ECN – in development
  - Fee for service
  - Blades up to 60-m.
- New and Renewable Energy Center (NaREC)
  - New test facilities being developed at former Blythe shipyard
  - Blades up to 70-m.
  - Planned Fee for service
  - Government Financed – £5,000,000

LM Blade Test Facility



WMC Group /Delft Facility

European Drivetrain Test Facilities

Testing: Gearbox vs. Drivetrain System

- Currently most drivetrain testing is limited to gearbox acceptance testing at the gear suppliers.
  - Flender, Eikoff, Metso, Hansen have gearbox test facilities.
  - Tests are limited to commercial gearboxes – innovations require new customer-financed test facilities.
- No comparable gearbox test facilities exist in the U.S. due to diminished gear industry.
- NREL operates the only integrated drivetrain test facility in the world.
  - Capable of testing full systems, gearboxes, direct drive generators, power electronics, and controls.
  - 2.5-MW capacity too low for current industry projects.
  - High demonstrated value in system integration testing.
- Proposed 12-MW Danish Dynamometer
  - Budget approximately $10M
  - Operated for service fee by Risoe Labs
  - Limited to gearbox testing

Finland - 6-MW Gearbox Test Facility at MESTO Drives

Integrated Drivetrain 2.5-MW Test Facility at NREL

Risks Without LWTTF

- Risk to the Wind Program:
  - Failure to meet mission needs and goals due to higher technology costs and non-competitive U.S. manufacturers
- Risk to U.S. Wind Industry:
  - Bankruptcy due to catastrophic component failures
  - Loss of market share to foreign manufacturers due to fleet-wide equipment failures and poor machine reliability

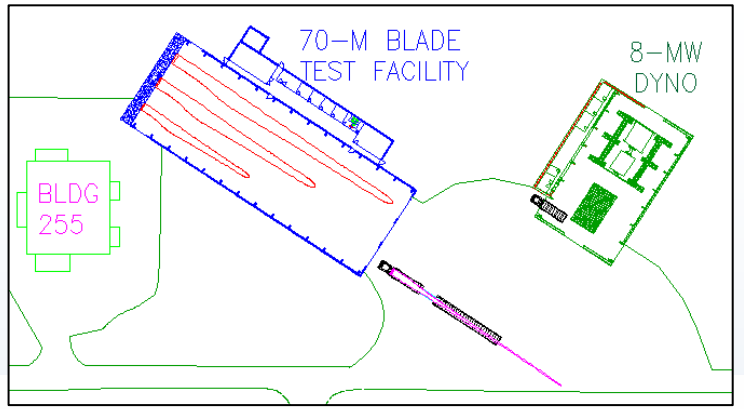
Current Status and Need

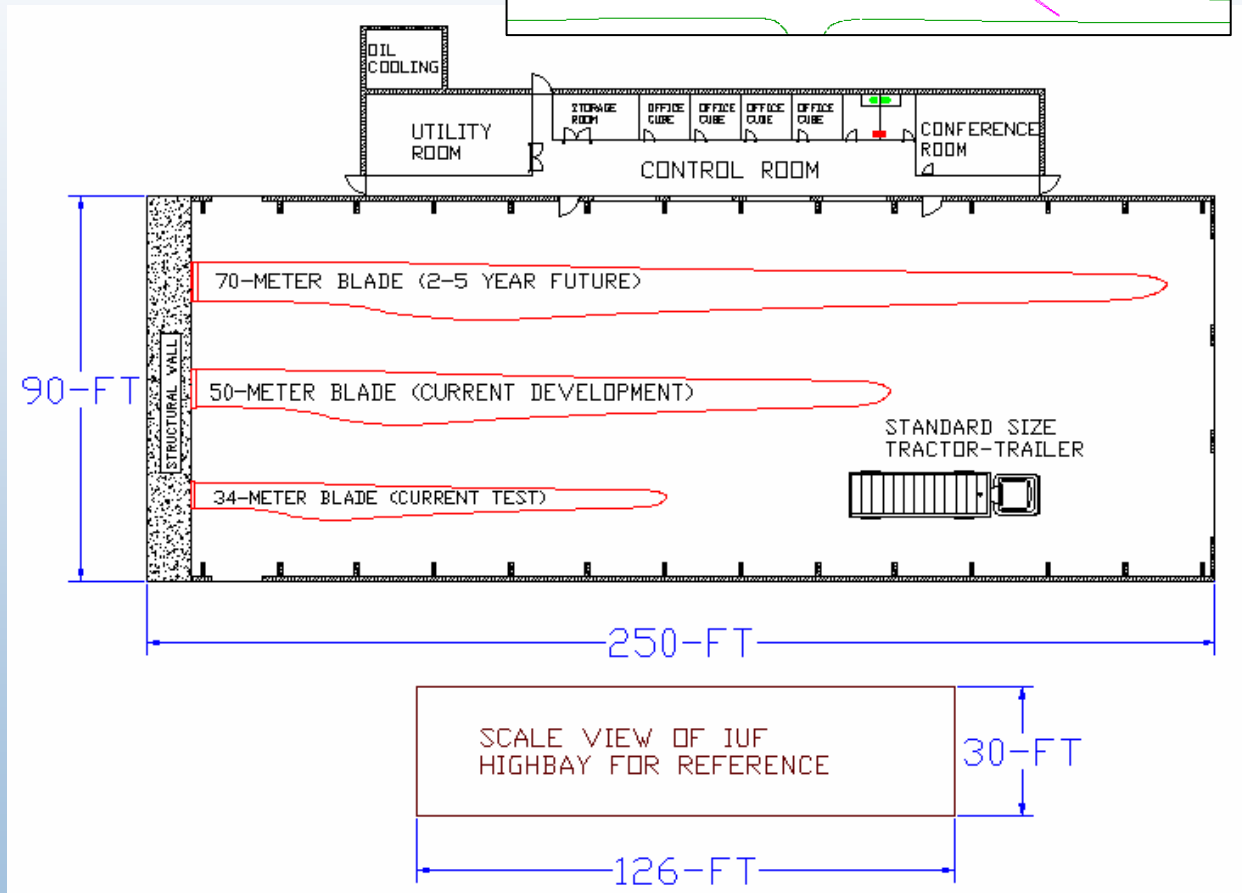
- US Wind Industry:
  - Skyrocketing at 30% growth rate per year
  - Has outgrown existing NWTC blade and dyno test facility capabilities (34 meter max, 1.5 MW turbine)

- Current DOE/NREL Industry Partners:
  - Building turbines in 2 – 3 MW size range
  - Immediate need for blade tests:
    - TPI: 44 m, MHI 2 MW (CRADA)
    - Clipper: 45 m, 2.5 MW (LWST)
    - GE Wind: 45 m, 2.x MW (LWST)
  - Have to resort to blade testing overseas
    - Low priority
    - Expensive
  - Looking for other blade test options

Ideal Solution: Large Wind Turbine Test Facilities

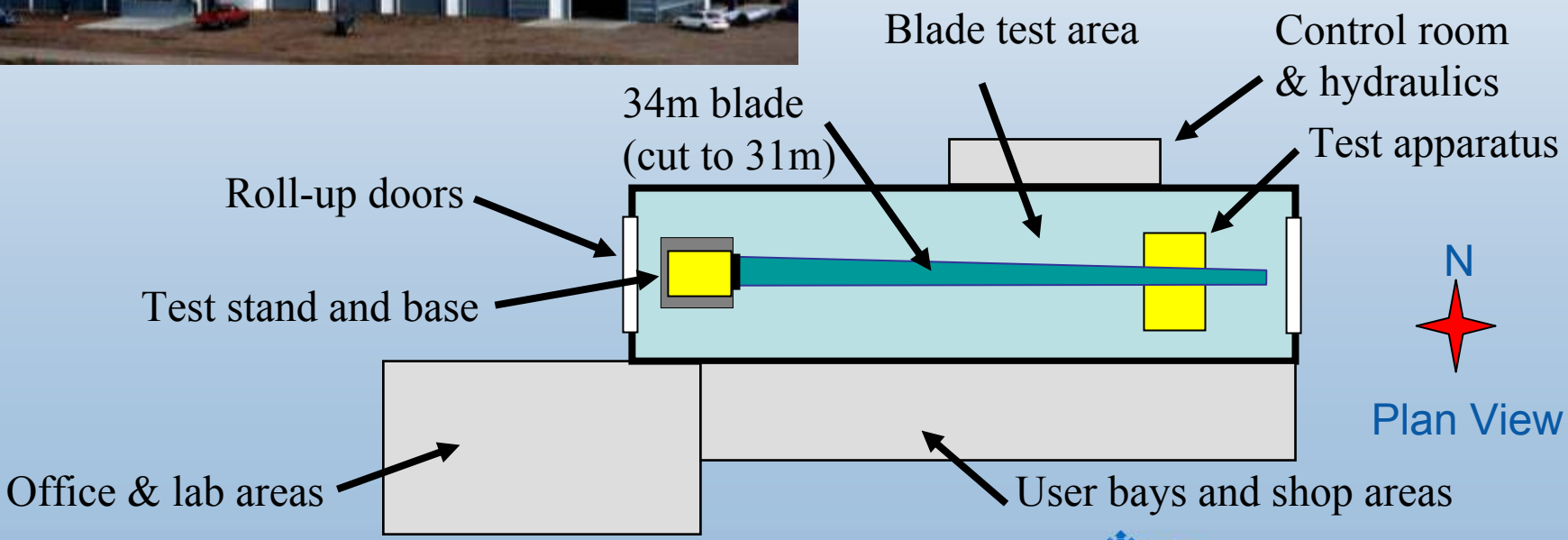
- Significantly delayed
  - Industry needs LWTTF now
  - Many hurdles yet to clear
  - Needs congressional approval and funding
  - Anticipated best-case completion FY'08
- Planned interim stop-gap blade test solutions
  - Stretch use of existing facility
  - Less than ideal, many limitations
- No interim dyno test solutions



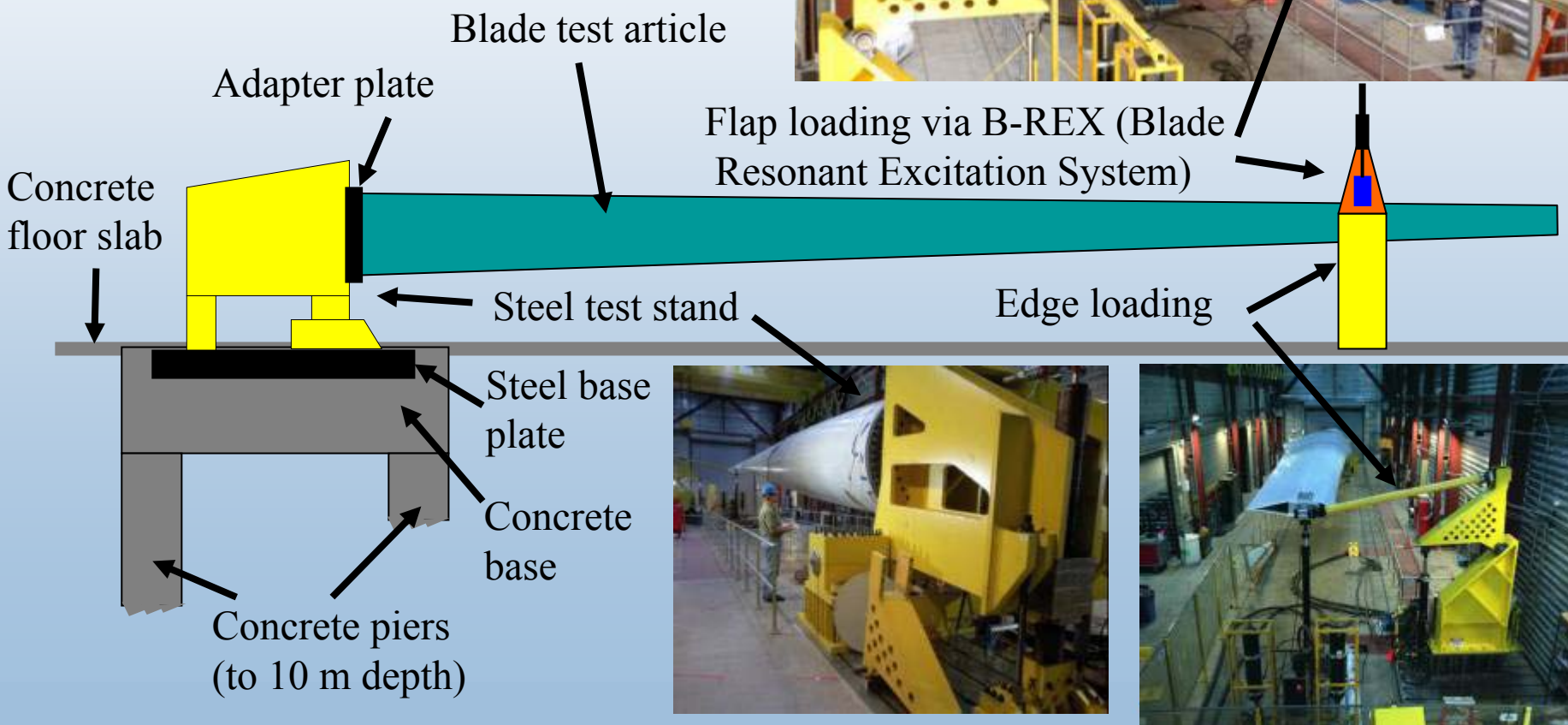


NWTC Industrial User Facility (IUF)
Existing Blade Test Capability

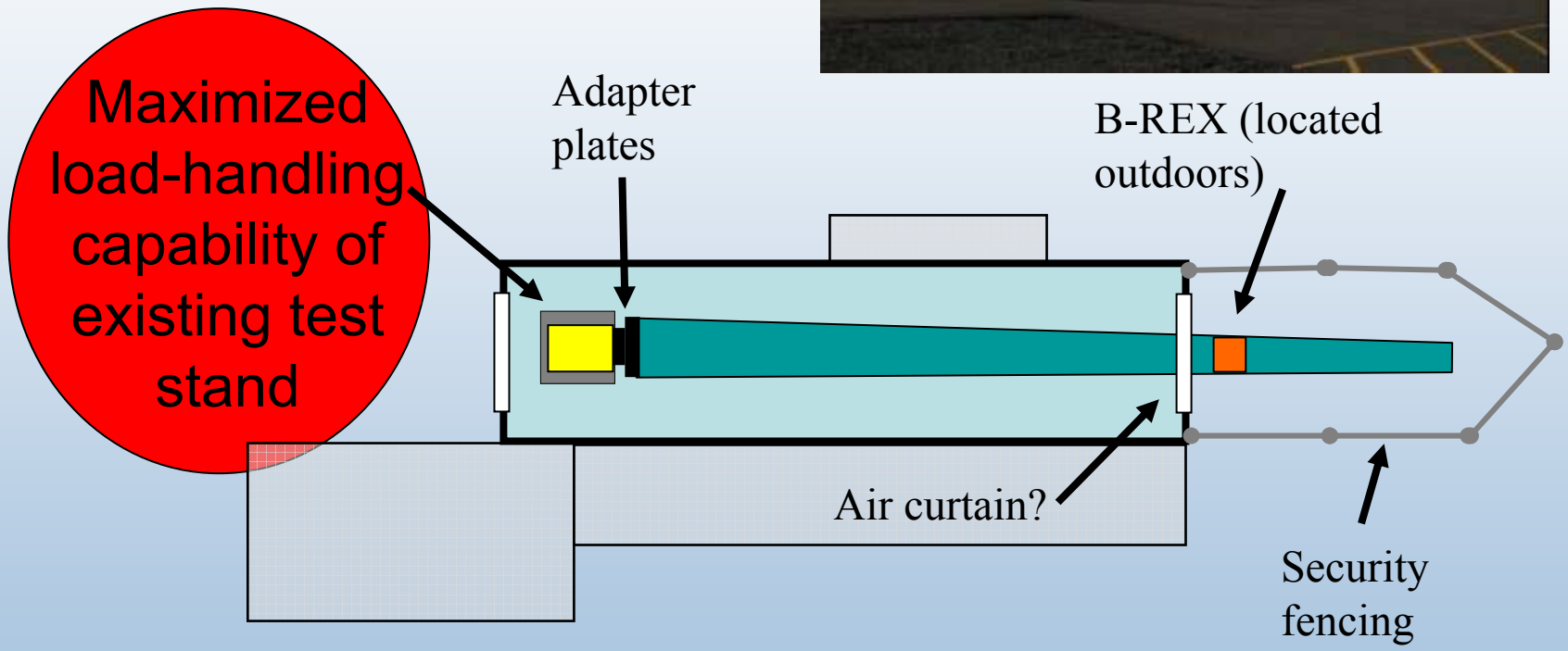
Can currently conduct static and fatigue testing of wind turbine blades up to 34 meters in length (1.5 MW turbines)



NWTC Industrial User Facility (IUF) Existing Blade Test Capability



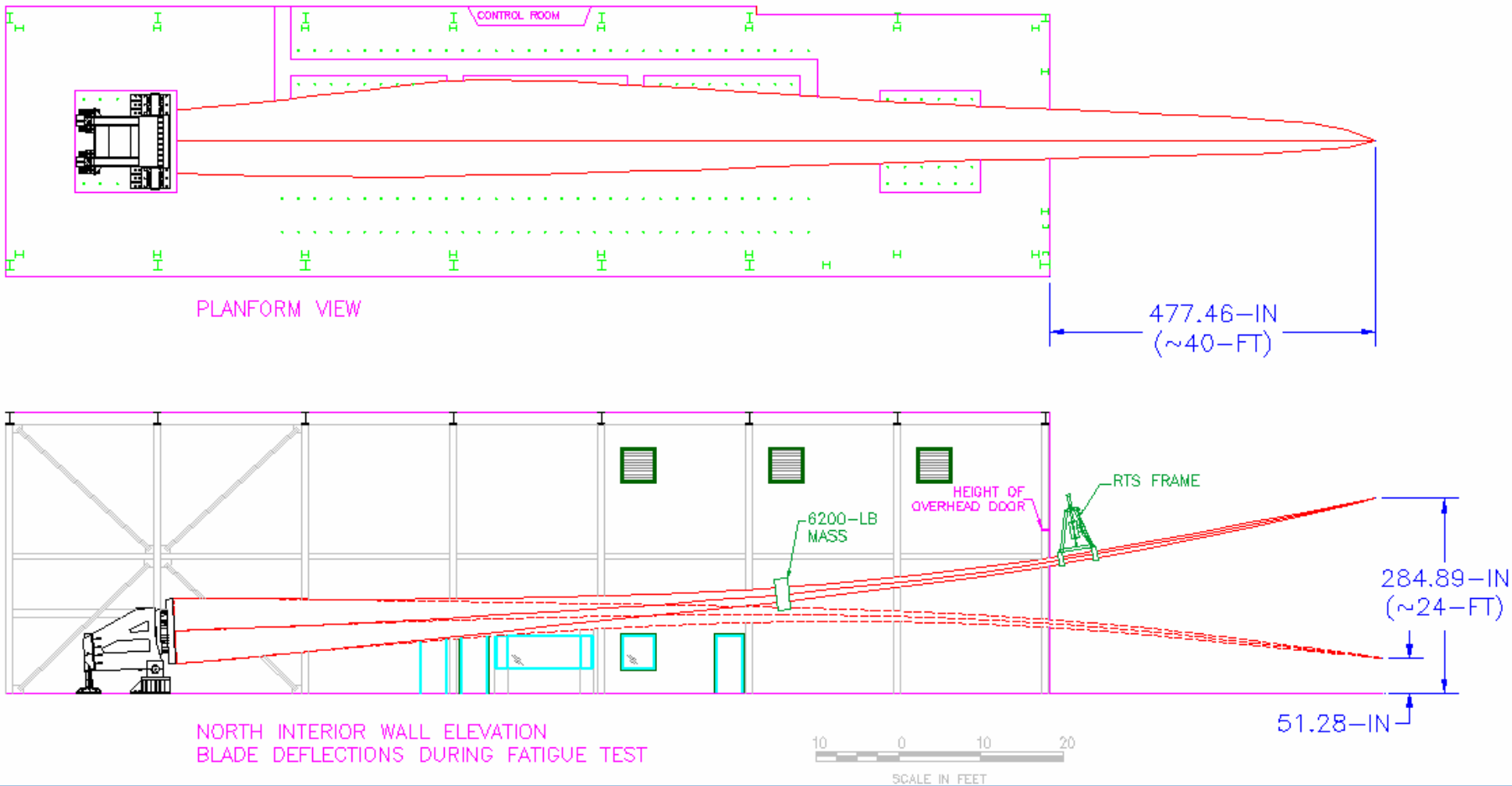
Stop-gap Blade Test Solution #1:



Single-axis fatigue testing of 44.7m TPI blade (funds-in CRADA)

Cannot conduct static testing or dual-axis testing

TPI 44.7–M BLADE INSTALLED IN IUF HIGHBAY



Stop-gap Blade Test Solution #2:

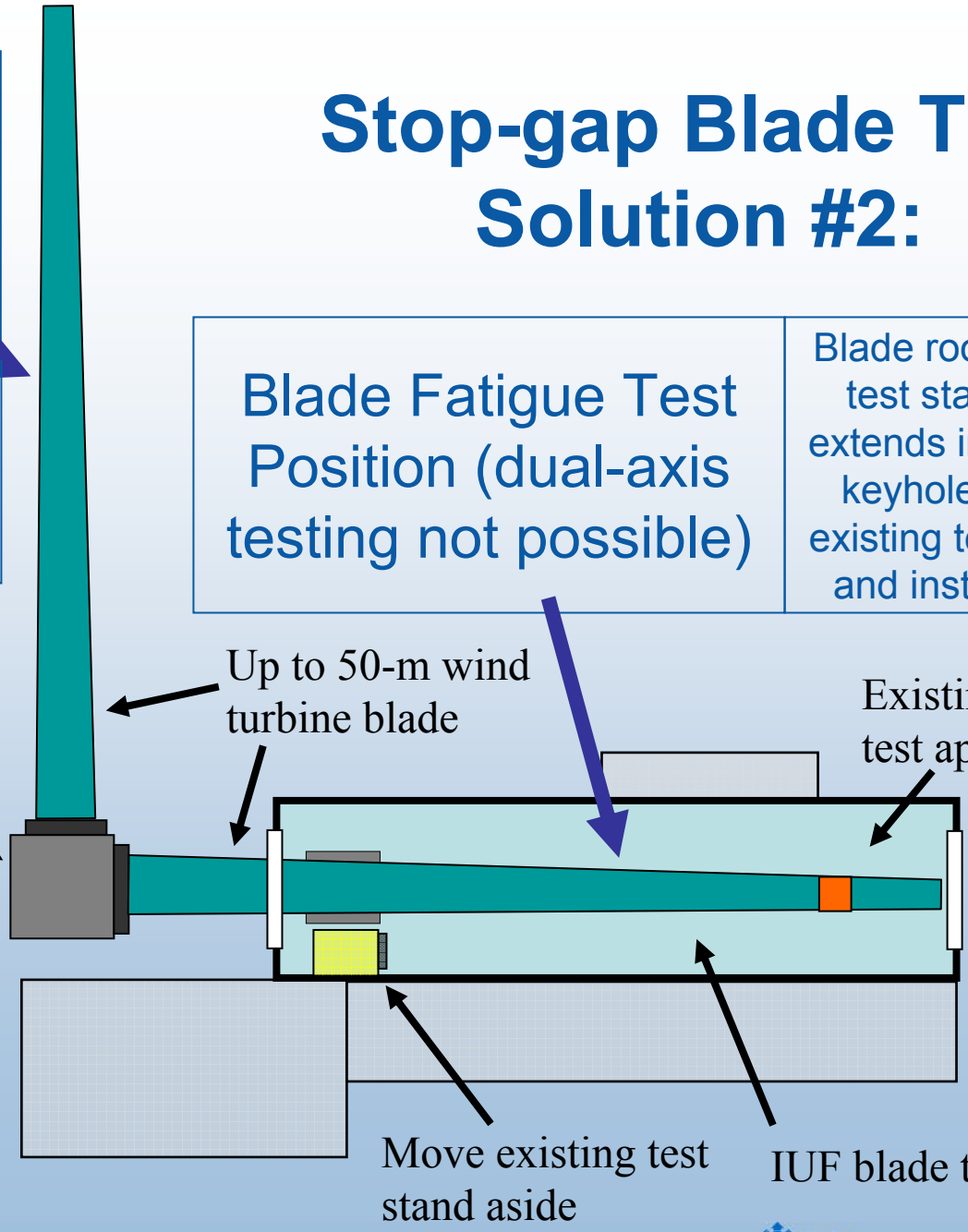
Blade Test Preparation and Static Test Position

Blade root attached to test stand tilts upward 20° to allow for static test deflection

Blade Fatigue Test Position (dual-axis testing not possible)

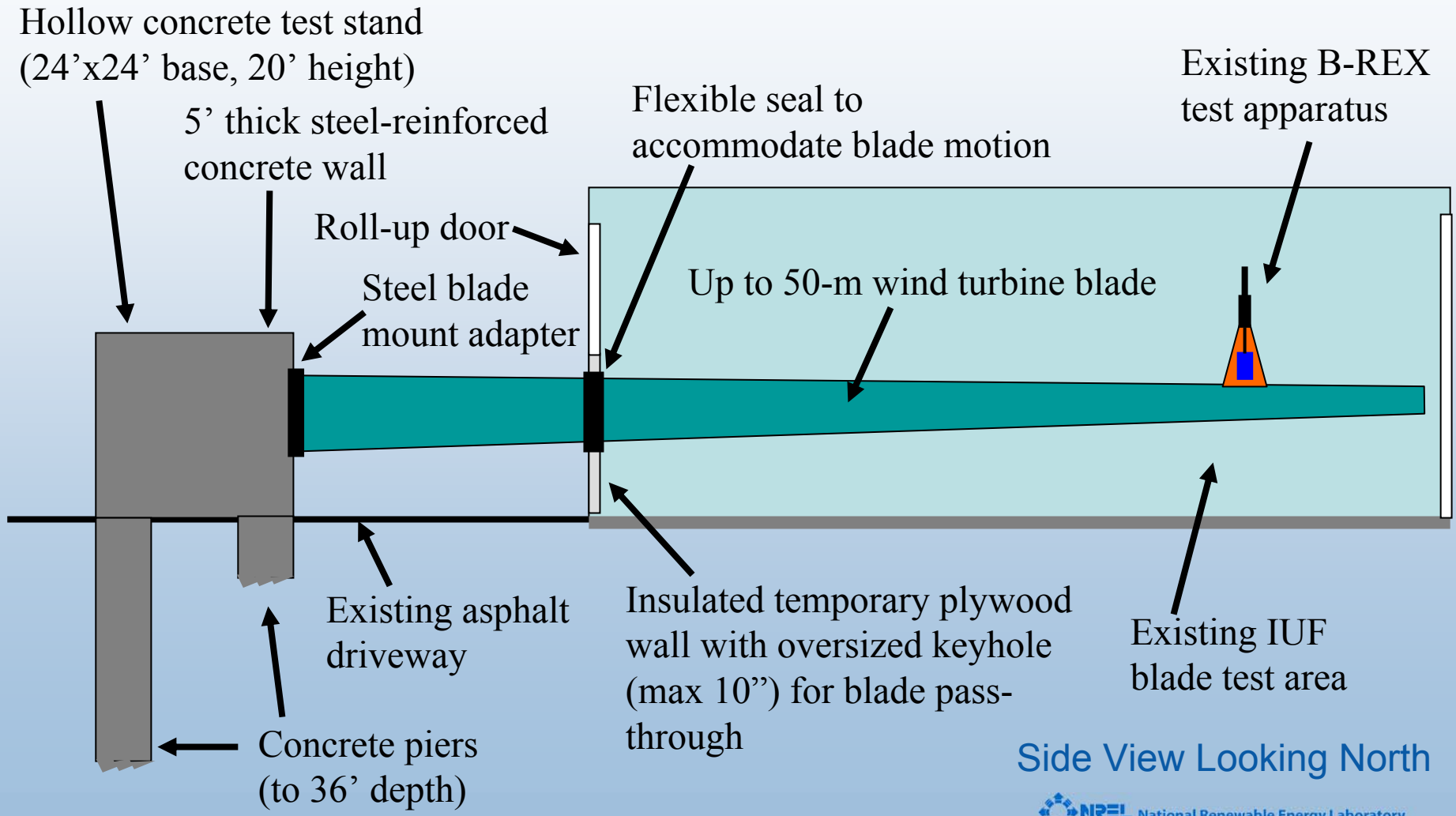
Blade root attached to test stand outside, extends inside through keyhole opening to existing test apparatus and instrumentation

Temporary concrete blade test stand – exp. completion 3/05



Temporary 50-m Blade Test Stand

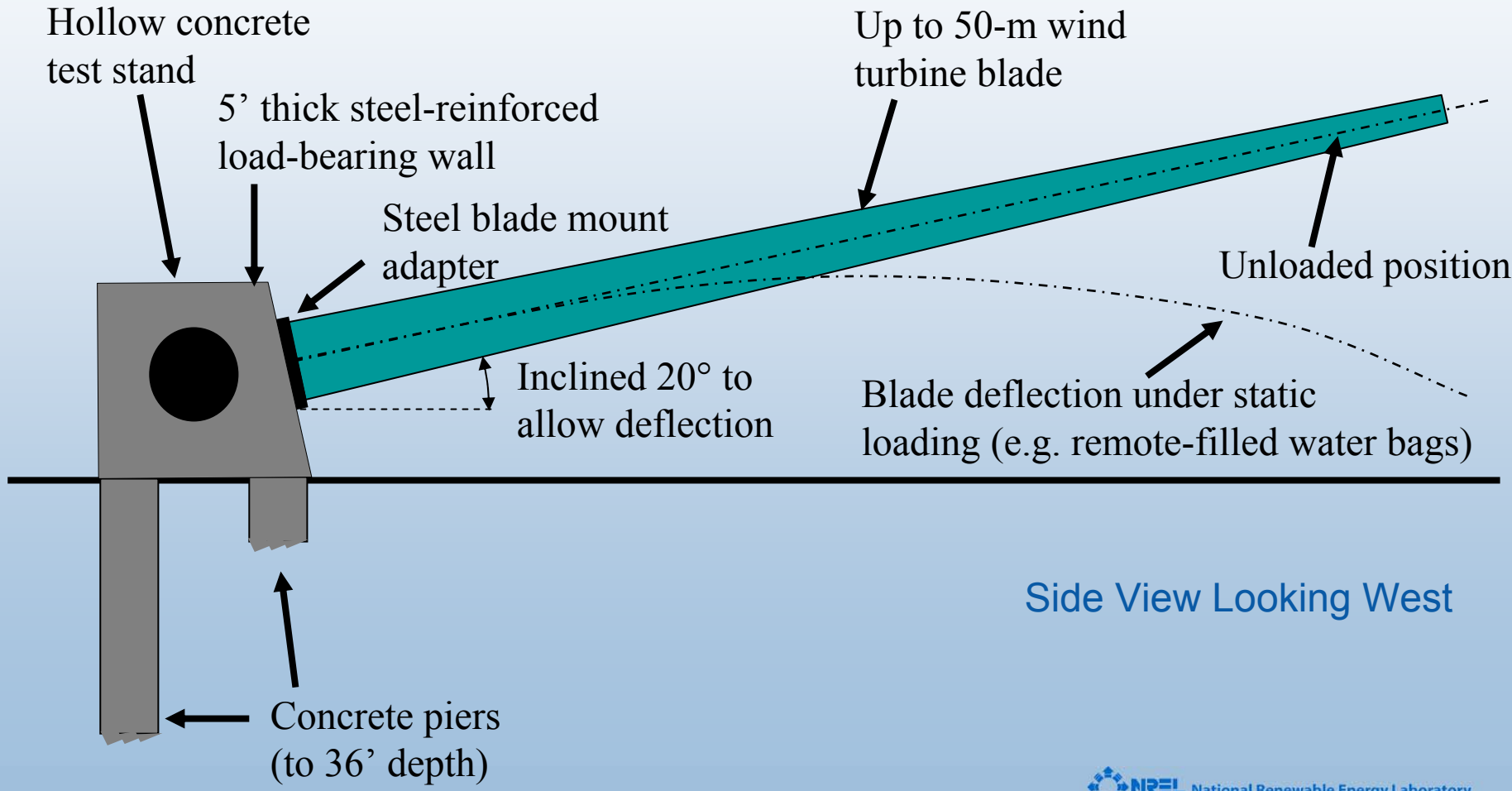
Blade Fatigue Test Position



Side View Looking North

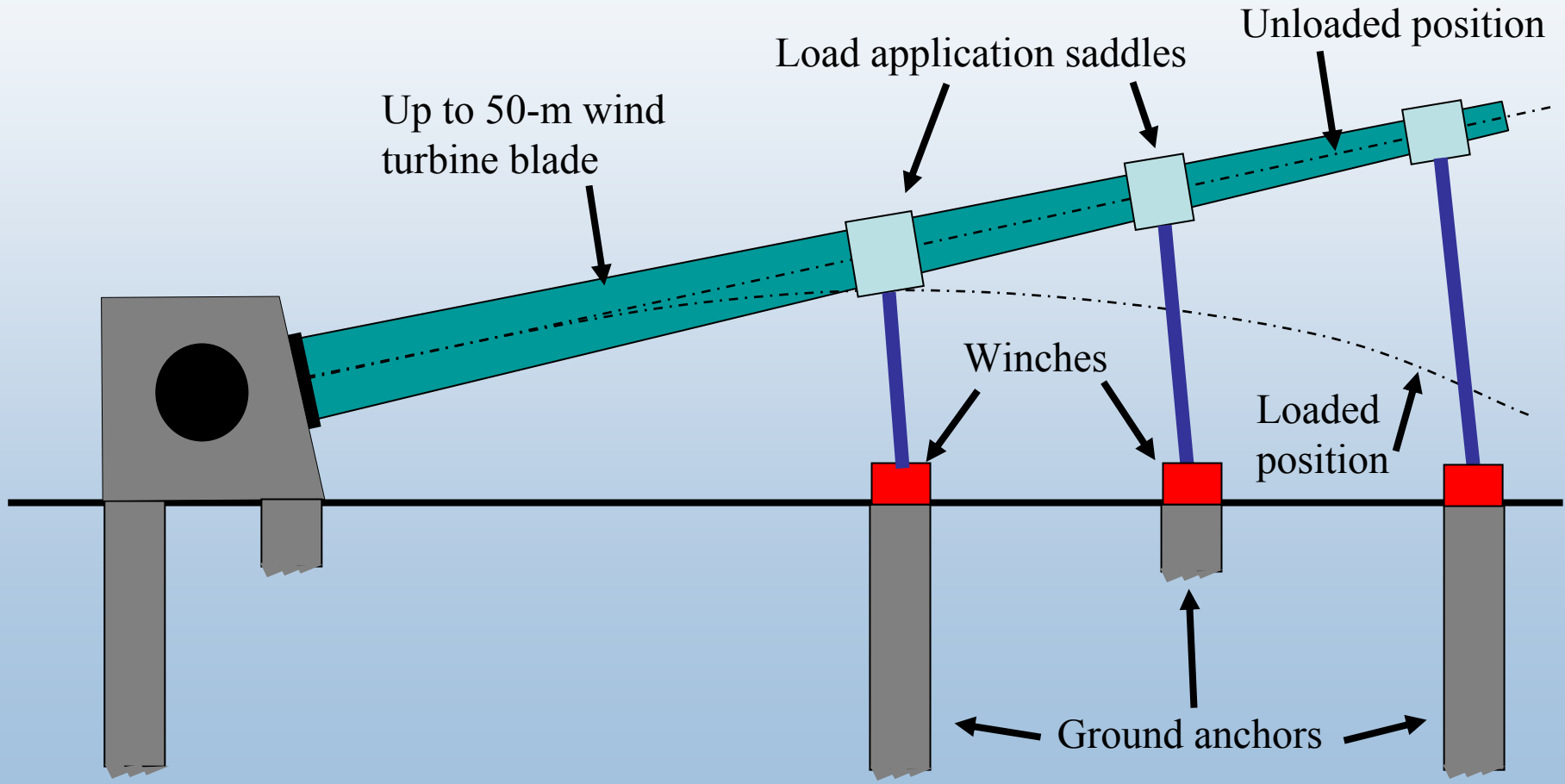
Temporary 50-m Blade Test Stand

Blade Test Preparation and Static Test Position



Side View Looking West

Temporary 50-m Blade Test Stand Static Blade Pull Test Capability (Planned for FY'06)



Temporary 50-m Blade Test Stand: Risks

- If Built: purpose may be misunderstood
  - Does not replace or delay need for LWTTF!
    - Can help US wind industry, but many limitations:
      - Cannot do simultaneous dual-axis testing, restricted edge loading
      - Cannot do static testing using IUF crane, pushes the limit of existing IUF test capabilities (other restrictions depending on blade size, weight, required deflection)
      - Weather and temperature difficulties
    - Much-reduced test efficiency
      - Test durations more than 2x longer (>6 months) to provide accredited data to certifying agencies
      - Some tests not possible
      - Helps reduce backlog of planned tests, but can't catch up
- If Not Built: US industry falls farther behind
  - Delays in certification, look for solutions elsewhere

Temporary 50-m Blade Test Stand: Lowest-cost Option

- To address immediate industry-partner blade test demands:
  - Accredited static (ultimate strength) and fatigue testing
  - Apply loading needed to test blades up to 50 meters
    - Flap bending max torque at blade root: ±1.6E7 N-m (±12,000,000 ft-lbs)
    - Edge bending max torque at blade root: ±6.1E6 N-m (±4,500,000 ft-lbs)
- Conducted engineering trade-off studies:
  - Simple, hollow block made of of steel-reinforced concrete, 24'x24', 20'high
  - Anchored to 4 concrete piers, each 36' deep
  - 5' thick structural load-carrying walls
  - Constructed outdoors, 35'- 40' from IUF door
  - Blades attach to stand and project into IUF to utilize existing test capabilities
    - hydraulics, test gear, instrumentation
- To be removed when LWTTF is completed
  - Tear-out strategy

Schedule and Budget

- Schedule
  - 2 months: Design contract placed & executed
  - 2 months: Competitive procurement solicitation
  - 3 months: Construction
  - Expecting completion March ’05
- Budget
  - Using Wind Program capital funds
  - Cost estimate: $400K (FY’04 & ‘05)
    - Design & engineering: $25K
    - Construction: $350K
    - Contingency: $25K
  - Ground anchors for static test pull: $50K (FY’06)

44.7m Blade Move